HOW SOLID IS OUR KNOWLEDGE OF SOLID WALLS? - COMPARING ENERGY SAVINGS THROUGH THREE DIFFERENT METHODS

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ABSTRACT

Recent UK-based studies have shown a performance gap between the energy performance of buildings calculated using tabulated thermophysical properties of solid walls and that estimated from in-situ measurements. Solid-walled buildings have been targeted by UK Government policies and incentive schemes to meet climate change mitigation targets and improve the efficiency of the building stock, as they are less efficient and more expensive to treat than cavity walls. Since it is common practice to estimate energy use and potential savings for buildings retrofit assuming standard values from the literature, the performance gap may have serious implications on the decision-making and the cost-effectiveness of energy-saving interventions.

The aim of this paper is to compare and contrast the results obtained from three different methods for estimating normalised dwelling energy demand:

a) the UK energy performance certificate (EPC) method, which uses the standard assessment procedure (SAP) with tabulated inputs (the business as usual case);

b) the SAP calculated using empirical air change rates from pressure tests and U-values estimated analysing monitored data with a Bayesian-based dynamic method developed by the authors;

c) a normalised annual consumption (NAC) method based on empirical energy consumption data from smart meter and weather data.

The analysis is performed on a sample of dwellings from the Energy Saving Trust "Solid Wall Field Trials" dataset. Results show that EPC estimates are systematically higher (between 7.5% and 22.0%) than SAP. Conversely, the NAC displayed a large range of relative differences (between -77% and +99%) compared to the EPC.

This raises questions about the relative merits and purpose of the EPC and SAP bottom up methods compared to the smart-meter data-driven NAC method. Further research is suggested using SAP 2009 to isolate the thermal component of energy demand and compare it directly with the NAC component.

Keywords: SAP, in-situ U-values, smart meters, heat losses, big data, Bayesian statistics

INTRODUCTION

The EU requires member states to develop an energy performance certificate (EPC) for residential properties to promote comparison of dwelling efficiency. EPCs are mandatory in the UK to either buy, rent or build a property [1]. The standard assessment procedure (SAP) underlies the EPC system in the UK. It defines a simplified model for estimating dwelling energy demand based on building design parameters, normalised for variance in occupancy and operation [2]. The EPC applies SAP to existing dwellings by using standard tabulated inputs for parameters that are not readily determined in an existing building.

The thermal transmittance, also known as U-value, of external walls is a key parameter in the SAP calculation [3]. Typically assumed U-values of solid walls have recently come under scrutiny, as estimates from in-situ heat-flux measurements found significantly lower values compared to the standard [4]. In most cases the thermophysical performance of solid walls was considerably better than expected with potentially significant implications on EPC consumption estimates, EPC rating and cost-effectiveness of retrofitting interventions. Therefore, interest has risen in understanding the impact that using measured values rather than tabulated data would have on the final outcomes. In this paper SAP calculation was obtained using measurements of the air change rate and estimations of the U-value of walls derived from a novel Bayesian-based approach to analyse in-situ measurements of heat flux and temperatures [5].

Monitoring of dwelling energy demand through smart metering is now becoming widespread due to EU and UK policy [6, 7], making available an unprecedented wealth of data that can be used to extract new information or to validate predictive models. In this paper, monitored consumption was compared with building-design-based EPC consumption estimates. A method is proposed to calculate a normalised annual consumption (NAC) from smart meter data, based on earlier work in this area [8, 9]. Normalisation of the measured demand was needed to compare NAC with EPC and SAP as the latter two approaches are not intended to predict real consumption in an occupied dwelling in a given year. Instead, they calculate demand normalised for occupancy, occupant behaviour, and variations in climate from year to year [2]. The application of SAP to predict actual yearly consumption can be misleading, undermining its purpose as shown in [10].

DATASET

The dataset analysed is a sample of dwellings from the Energy Saving Trust “Solid Wall Insulation Field Trial” project, which aimed at performing deep energy efficiency retrofits on solid-walled buildings (brick and stone) across the UK [11, 12]. We used pre-retrofit data collected through site surveys, including SAP/EPC calculations, air tightness tests and heat flux and air temperature measurements on two close locations of a representative wall.

Due to limitations and issues in the dataset, a subset of dwellings was selected by imposing the following criteria:

- non-ambiguous address to associate climate data and gas calorific values;
- complete pre-retrofit SAP survey;
- both electricity and gas smart meter data covering the period;
- non corrupted consumption measurements. Dwellings with over 100 kW daily average demand (around 50 times the national average [13]) were discarded;
- heat flux and temperature measurements for the period;
- a difference between minimum and maximum temperatures of at least 8˚C (a requirement of the normalised consumption method);
- relative difference of the two estimated U-values less than 10% [11].

A total of 13 sites from the original 83 in the data provided were retained for this analysis. External temperature data [14] was associated with each dwelling based on its address. Gas energy use was calculated from the smart meter volumetric readings according to the National Grid method [15] using historical daily calorific values retrieved for each building location.

METHOD

A three-way comparison was performed between the yearly energy consumption per unit area calculated using: SAP, EPC, and NAC.

The SAP 2005 [2] revision was used as this was the version adopted in the original study [11]. The worksheets calculated energy consumption using ventilation rates and U-values derived from in-situ measurements. U-values were estimated according to the single thermal mass method developed by the authors and described in [5].

The UK EPC energy demand estimate is defined as SAP applied using standard tabulated values for those inputs where measured values are not available (facilitating its applicability to existing buildings).

The NAC value was derived from smart meter data using a variation of the PRISM method described in [8] and building on the work in [9]. In brief, this method uses a 3-parameter consumption model where the total power (P_{tot}) is estimated as:

$$\begin{cases} P_{\text{tot}} = \text{PGT}(T_{\text{ext}} - T_{\text{ref}}) + P_{\text{bl}} & T_{\text{ext}} < T_{\text{ref}} \\ P_{\text{tot}} = P_{\text{bl}} & T_{\text{ext}} \geqslant T_{\text{ref.}} \end{cases} \quad (1)$$

The power temperature gradient (PTG), the baseload power (P_{bl}), and the reference temperature (T_{ref}) are determined by fitting to daily average total consumption and external temperature (T_{ext}) for a given dwelling.

NAC is the sum of monthly demand calculated using SAP reference monthly average temperatures (analogously to PRISM which used US temperatures) [2, 8]. When calculating NAC, T_{ref} is replaced by the SAP external reference temperature to normalise for occupant choice of heating set-point, which in turn determines T_{ref}. PTG and P_{bl} are independent of T_{ref}, so this matches the SAP assumptions for occupant behaviour and makes NAC and SAP commensurable. Per unit area values were obtained using the floor area from the surveys.

RESULTS AND DISCUSSION

The yearly consumption per unit area calculated through each method is shown in Figure 1.

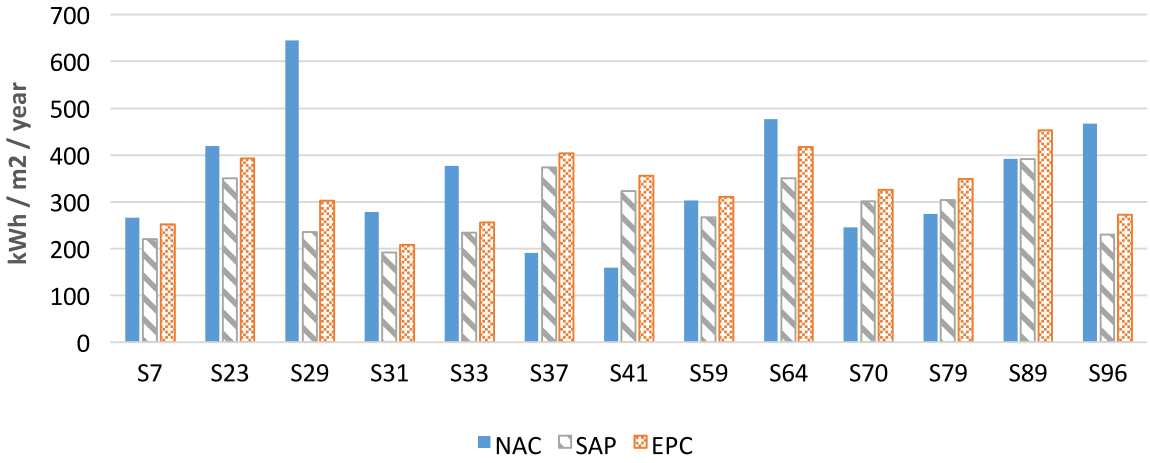

Figure 1: Yearly energy consumption per unit area for each dwelling obtained from the EPC (tabulated values), the SAP (air change rates and U-values from measurements) and the NAC (smart meter data) methods.

Using measured U-values and air change rates reduces the SAP estimate between -7.5% and -22.0% relative to the EPC estimate. The measured U-value, with an average of 1.4 W/m²K (ranging between 0.7 and 1.8 W/m²K), is considerably lower than the standard value of 2.1 W/m²K for solid walls. The external heating reference temperature, derived in the SAP method from the dwelling thermal properties and gains, saw a corresponding average decrease of 0.4˚C (between -0.2˚C and -1.0˚C). As a result, energy consumption per square metre estimated by SAP decreased by 12.0% on average (between -7.5% and -22.0%) compared to the EPC (Figure 2).

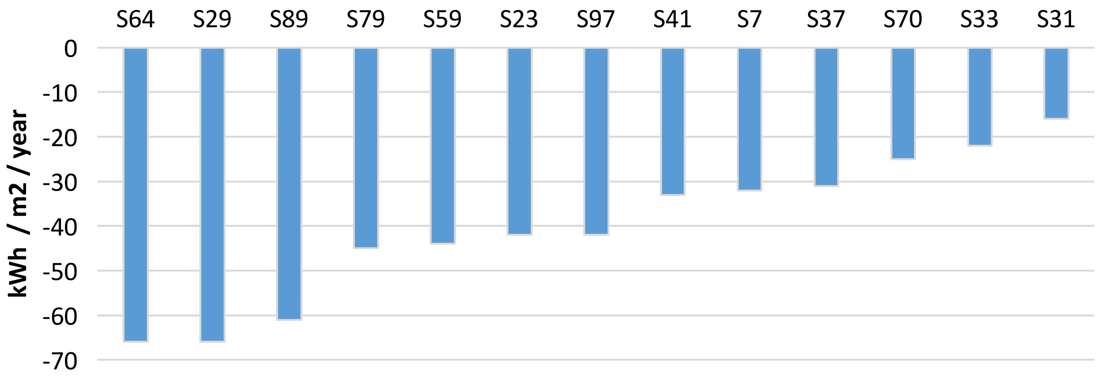

Figure 2: Difference in the yearly energy consumption per unit area of EPC and SAP.

Conversely, the NAC values from measured consumption were on average 14.1% higher than the EPC estimates. However, as is clear from Figure 3 (left), the range of differences is very large and does not follow any evident pattern. While a few sites remain within 10.0% of the EPC estimate, others diverge considerably with differences ranging from -77.0% to +99.0%.

The NAC is on average 0.4% higher than the SAP estimate. However this may be misleading as shown in Figure 3 (right). The divergence is even larger than with the EPC, with NAC ranging from -74.0% below to +155.0% above SAP. Using measured data in the SAP model surprisingly resulted in worse agreement. There are many potential causes for the difference between EPC and NAC estimates of energy use, including:

- NAC accounting for a baseload term which can differ from the EPC assumption;
- U-values of roofs and windows;
- hidden thermal bridges;
- efficiencies of heating systems which may differ from manufacturer quotes.

To identify sources of difference between SAP and NAC, a partial comparison using only the PTG thermal loss component could be performed. To obtain a PTG from SAP, monthly energy demand values are needed. The SAP 2009 revision [16] of the standard added monthly estimates, but it was not used here since the trial used SAP 2005. Future work could use SAP 2009 to perform this comparison.

The results could be further consolidated by recovering additional sites by repairing the input data. Dwellings with full heat-flux and ventilation rate measurements are rare, as current methods for the evaluation of U-values from in-situ measurements require long monitoring campaigns (up to two weeks) and are seasonally bounded to the wintertime [5]. Therefore, the immediate prospective dataset is limited to the 85 dwellings in the Solid Wall Field Trial. However, the U-value estimation method developed by Biddulph [5] could enable more buildings to be tested rapidly, as its dynamic Bayesian-based approach needs shorter time series and can in principle be used in all seasons. Smart meter data should also be extensively available in the near future. It would be particularly interesting to compare results for different wall types.

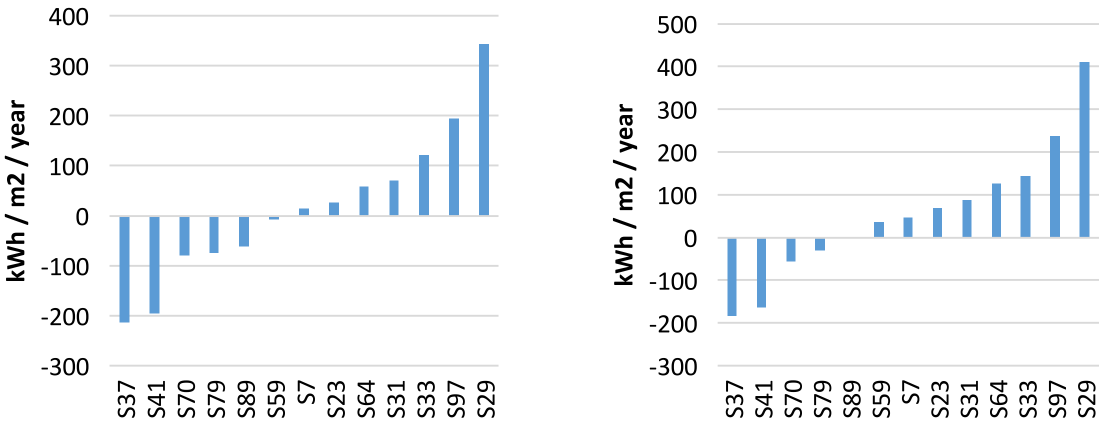

Figure 3: Difference between NAC and EPC (left) and SAP (right).

CONCLUSION

This study performed a three-way comparison between the EPC - which is the standard method for characterising dwelling energy demand, SAP - which uses the same model but with measured rather than tabulated air change rates and wall U-values, and NAC - which normalises measured energy consumption for reference temperature. Thirteen sites with good quality data were selected from the "Solid Wall Field Trials" dataset [11, 12]. It was found that EPC estimates of energy demand for solid-walled buildings were systematically higher (between +7.5% and +22.0%) compared to SAP. However, the NAC varied greatly compared to SAP and EPC, with values of yearly energy demand per square meter as low as -77% below the EPC rating and as high as +99% above it. Future work could consolidate this result by enlarging the sample and extending the analysis to other wall types. The use of SAP 2009 [16], which includes a power-temperature-gradient thermal loss term, could also enable the direct comparison SAP and NAC approaches eliminating potential sources of uncertainty.

This study raises questions about the relative representativeness and applicability of the three methods investigated. EPC does not address as-built performance or in-use behaviour as it is only based on models, visual inspections, building plans and standard tabulated thermophysical properties. Although SAP tries to overcome this limitation by introducing the possibility of using measured properties instead of tabulated ones, it uses spot measurements that may still not account for all aspects contributing to the overall thermal performance of a real dwelling, such as ventilation practices and occupants' thermal comfort. This highlights the challenge of using modelling tools to estimate real building performance.

Smart-meter data-driven methods like NAC may represent a solution to provide a whole-house as-built performance and reconcile models and measurements. However, these approaches may lead to highly variable results as they encapsulate a range of unknowns (e.g., occupants' behaviour, materials performance or build quality) that may be difficult to isolate and quantify. This poses the question whether different assessment tools should be considered to assess the design or the whole system performance to reflect the goals of the evaluation.

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REFERENCES

1. UK-Gov: Buying or selling your home - GOV.UK. Retrieved May 7, 2015, https://www.gov.uk/buy-sell-your-home/energy-performance-certificates .
2. BRE: SAP2005 - The Government's Standard Assessment Procedure for Energy Rating of Dwellings. 2005.
3. Hughes, M., Palmer, J., Cheng, V., Shipworth, D.: Global sensitivity analysis of England's housing energy model. Journal of Building Performance Simulation, 2014.
4. Li, F.G.N., Smith, A.Z.P., Biddulph, P., Hamilton, I.G., Lowe, R., Mavrogianni, A., Oikonomou, E., Raslan, R., Stamp, S., Stone, A., Summerfield, A.J., Veitch, D., Gori, V., Oreszczyn, T.: Solid-wall U-values: heat flux measurements compared with standard assumptions. Building Research & Information, 43(2), 1-15, 2015.
5. Biddulph, P., Gori, V., Elwell, C. A., Scott, C., Rye, C., Lowe, R., & Oreszczyn, T.: Inferring the thermal resistance and effective thermal mass of a wall using frequent temperature and heat flux measurements. Energy and Buildings, 78, 10-16, 2014.
6. European Comission: Over 70% European consumers to have a smart meter for electricity by 2020. 2014. Retrieved October 1, 2014, https://ec.europa.eu/jrc/en/news/over-70-percent-european-consumers-have-smart-meter-electricity-2020 .
7. DECC: Smart meters - Helping households to cut their energy bills - Policies - GOV.UK. 2014. Retrieved March 18, 2014, https://www.gov.uk/government/policies/helping-households-to-cut-their-energy-bills/supporting-pages/smart-meters .
8. Fels, M. F.: PRISM: An introduction. Energy and Buildings, 9(1-2), 5–18, 1986.
9. Summerfield, A. J., Oreszczyn, T., Hamilton, I. G., Shipworth, D., Huebner, G. M., Lowe, R. J., & Ruyssevelt, P.: Empirical variation in 24-h profiles of delivered power for a sample of UK dwellings: Implications for evaluating energy savings. Energy and Buildings, 88, 193-202, 2015.
10. Kelly, S., Crawford-Brown, D., & Pollitt, M. G.: Building performance evaluation and certification in the UK: Is SAP fit for purpose? Renewable and Sustainable Energy Reviews, 16(9), 6861–6878, 2012.
11. Birtchall, S., Pearson, C., Brown, R.: Solid Wall Insulation Field Trial - Baseline Performance of the Property Sample. Report 53588/x, BSRIA Limited, Bracknell (UK), 2011.
12. Stevens, G., & Bradford, J.: Do U-value insulation ? England's field trial of solid wall insulation. Eceee 2013 Summer Study, 1269–1280, 2013.
13. DECC: Domestic energy consumption in the UK between 1970 and 2012. In *Energy Consumption in the UK*, 2013.
14. Sharp, E., Dodds, P., Barrett, M., & Spataru, C.: Evaluating the accuracy of CFSR reanalysis hourly wind speed forecasts for the UK, using in situ measurements and geographical information. *Renewable Energy*, *77*, 2015.
15. NationalGrid: Calorific Value Information. Retrieved April 17, 2015, http://www2.nationalgrid.com/UK/Industry-information/Gas-transmission-operational-data/calorific-value-description/ .
16. BRE: SAP2009 - The Government's Standard Assessment Procedure for Energy Rating of Dwellings. 2009.